Chapter 5. Macrobenthic Communities

INTRODUCTION

Benthic macroinvertebrates along the coastal shelf of southern California represent a diverse faunal community that is important to the marine ecosystem (Fauchald and Jones 1979, Thompson et al. 1993a, Bergen et al. 2001). These animals serve vital functions in wide ranging capacities (Snelgrove et al. 1997). For example, some species decompose organic material as a crucial step in nutrient cycling; other species filter suspended particles from the water column, thus affecting water clarity. Many species of benthic macrofauna also are essential prey for fish and other organisms.

Human activities that impact the benthos can sometimes result in toxic contamination, oxygen depletion, nutrient loading, or other forms of environmental degradation. Certain macrofaunal species are sensitive to such changes and rarely occur in impacted areas, while others are opportunistic and can persist under altered conditions (Gray 1979). Because various species respond differently to environmental stress, monitoring macrobenthic assemblages can help to identify anthropogenic impact (Pearson and Rosenberg 1978, Bilyard 1987, Warwick 1993, Smith et al. 2001). Also, since many animals in these assemblages are relatively stationary and long-lived, they can integrate local environmental conditions (Hartley 1982, Bilyard 1987). Consequently, the assessment of benthic community structure is a major component of many marine monitoring programs, which are often designed to document both existing conditions and trends over time.

Overall, the structure of benthic communities may be influenced by many factors including depth, sediment composition and quality (e.g., grain size distribution, contaminant concentrations), oceanographic conditions (e.g., temperature, salinity, dissolved oxygen, ocean currents), and biological factors (e.g., food availability, competition, predation). For example, benthic assemblages on the coastal shelf off San Diego typically vary along sediment particle size and/or depth gradients. Therefore, in order to determine whether changes in community structure are related to human impacts, it is necessary to have an understanding of background or reference conditions for an area. Such information is available for the area surrounding the South Bay Ocean Outfall (SBOO) and the San Diego region in general (e.g., City of San Diego 1999, 2000; Ranasinghe et al. 2003, 2007).

This chapter presents analyses and interpretation of the macrofaunal data collected at fixed stations surrounding the SBOO during 2008. Descriptions and comparisons of the different macrofaunal assemblages that inhabit soft bottom habitats in the region and analysis of benthic community structure are included.

MATERIALS AND METHODS

Collection and Processing of Samples

Benthic samples were collected during January and July 2008 at 27 stations surrounding the SBOO (Figure 5.1). These stations range in depth from 18 to 60 m and are distributed along four main depth contours. Listed from north to south along each contour, these stations include: I35, I34, I31, I23, I18, I10, and I4 (19-m contour); I33, I30, I27, I22, I14, I16, I15, I12, I9, I6, I2, and I3 (28-m contour); I29, I21, I13, and I8 (38-m contour); I28, I20, I7, and I1 (55-m contour). Stations considered "nearfield" herein (I12, I14, I15, I16) are located within 1000 m of the outfall wye.

Samples for benthic community analyses were collected from two replicate 0.1-m^2 van Veen grabs per station during the 2008 surveys. An additional grab was collected at each station for sediment quality analysis (see Chapter 4). The criteria to ensure consistency of grab samples established by the United States Environmental

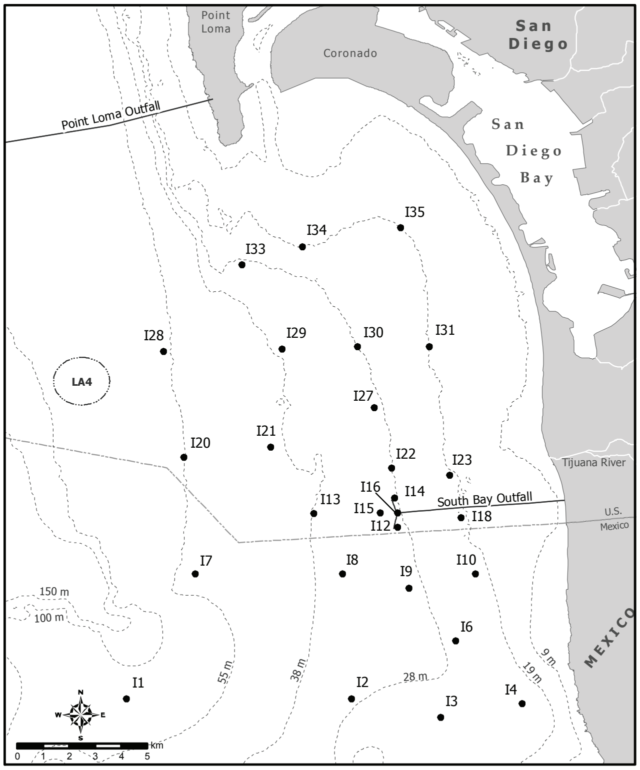


Figure 5.1
Macrobenthic station locations, South Bay Ocean Outfall Monitoring Program.

Protection Agency (USEPA) were followed with regard to sample disturbance and depth of penetration (USEPA 1987). All samples were sieved aboard ship through a 1.0 mm mesh screen. Organisms retained on the screen were relaxed for 30 minutes in a magnesium sulfate solution and then fixed in buffered formalin. After a minimum of 72 hours, each sample was rinsed with fresh water and transferred to 70% ethanol. All animals were sorted from the debris into major taxonomic groups by a subcontractor and then identified to species or the lowest taxon possible and enumerated by City of San Diego marine biologists.

Data Analyses

The following community structure parameters were calculated for each station per 0.1-m^2 grab: species richness (number of species), abundance (number of individuals), Shannon diversity index (H'), Pielou's evenness index (J'), Swartz dominance (Swartz et al. 1986, Ferraro et al. 1994), and the BRI or benthic response index (Smith et al. 2001). Additionally, the total or cumulative number of species over all grabs was calculated for each station.

Multivariate analyses were performed using PRIMER software to examine spatio-temporal patterns in the overall similarity of benthic assemblages in the region (Clarke 1993, Warwick 1993, Clarke and Gorley 2006). These analyses included classification (cluster analysis) by hierarchical agglomerative clustering with group-average linking and ordination by non-metric multidimensional scaling (MDS). The macrofaunal abundance data were square-root transformed and the Bray-Curtis measure of similarity was used as the basis for classification. SIMPROF (similarity profile) analysis was used to confirm non-random structure of the dendrogram (Clarke et al. 2008). SIMPER (similarity percentages) analysis was used to identify individual species that typified each cluster group. Patterns in the distribution of macrofaunal assemblages were compared to environmental variables by overlaying the physico-chemical data onto MDS plots based on the biotic data (Field et al. 1982, Clarke and Ainsworth 1993).

Results and Discussion

Community Parameters

Species Richness

A total of 778 macrobenthic taxa (mostly species) were identified during 2008. Of these, 22% (n=169) represented rare taxa that were recorded only once. The average number of taxa per 0.1-m^2 grab ranged from 39 to 143, and the cumulative number of taxa per station ranged from 95 to 304 (Table 5.1). This wide variation in species richness is consistent with patterns seen in previous years, and can probably be attributed to the presence of different habitat (or microhabitat) types in the region (see City of San Diego 2006–2008). Higher numbers of species, for example, have typically occurred at stations such as I28 and I29 (see City of San Diego 2008).

Table 5.1

Summary of macrobenthic community parameters for SBOO stations sampled during 2008. SR=species richness, no. species/0.1 m^2; Tot Spp=cumulative no. species for the year; Abun=abundance, no. individuals/0.1 m^2; H'=Shannon diversity index; J'=evenness; Dom=Swartz dominance; BRI=benthic response index. Nearfield stations in bold. Data are expressed as annual means (n=4); SE=standard error.

Station	SR	Tot spp	Abun	H'	J'	Dom	BRI
19-m stations							
I35	89	175	586	3.3	0.75	19	30
I34	49	127	887	1.9	0.49	5	12
I31	56	114	206	3.1	0.78	18	19
I23	73	189	309	3.5	0.83	21	20
I18	51	112	191	2.9	0.74	16	17
I10	68	140	246	3.4	0.81	24	19
I4	45	123	169	3.2	0.86	17	11
28-m stations							
I33	122	246	710	3.5	0.73	25	26
I30	83	180	288	3.7	0.84	28	23
I27	76	163	281	3.4	0.79	24	24
I22	78	195	305	3.4	0.79	25	23
I14	**94**	**184**	**437**	**3.5**	**0.78**	**26**	**23**
I16	**74**	**174**	**438**	**2.7**	**0.62**	**13**	**22**
I15	**75**	**165**	**703**	**2.2**	**0.51**	**7**	**23**
I12	**83**	**197**	**466**	**2.9**	**0.65**	**16**	**20**
I9	112	240	588	3.7	0.78	29	23
I6	71	148	1203	1.8	0.44	5	17
I2	39	95	198	2.3	0.63	8	18
I3	39	98	349	2.2	0.61	6	11
38-m stations							
I29	132	304	664	3.8	0.80	34	17
I21	60	136	311	2.8	0.68	13	8
I13	60	134	398	2.5	0.63	11	15
I8	61	132	301	2.7	0.66	14	18
55-m stations							
I28	143	267	523	4.4	0.89	49	14
I20	44	116	159	3.1	0.83	15	12
I7	52	119	131	3.5	0.88	22	7
I1	76	169	253	3.7	0.86	27	14
Mean	74	165	419	3.1	0.73	19	18
SE of Mean	5	10	48	0.1	0.02	2	1
Min	39	95	131	1.8	0.44	5	7
Max	143	304	1203	4.4	0.89	49	30

In addition, species richness varied between the two 2008 surveys, averaging about 6% higher in summer than in winter. Although species richness varied spatially and temporally, there were no apparent patterns relative to distance from the outfall (Figure 5.2A).

Polychaete (Annelida) worms comprised the greatest proportion of species per site during 2008, followed by crustaceans (Arthropoda), molluscs, echinoderms, and all other phyla combined (Table 5.2). These proportions generally are similar to those observed during previous years (e.g., see City of San Diego 2000, 2008).

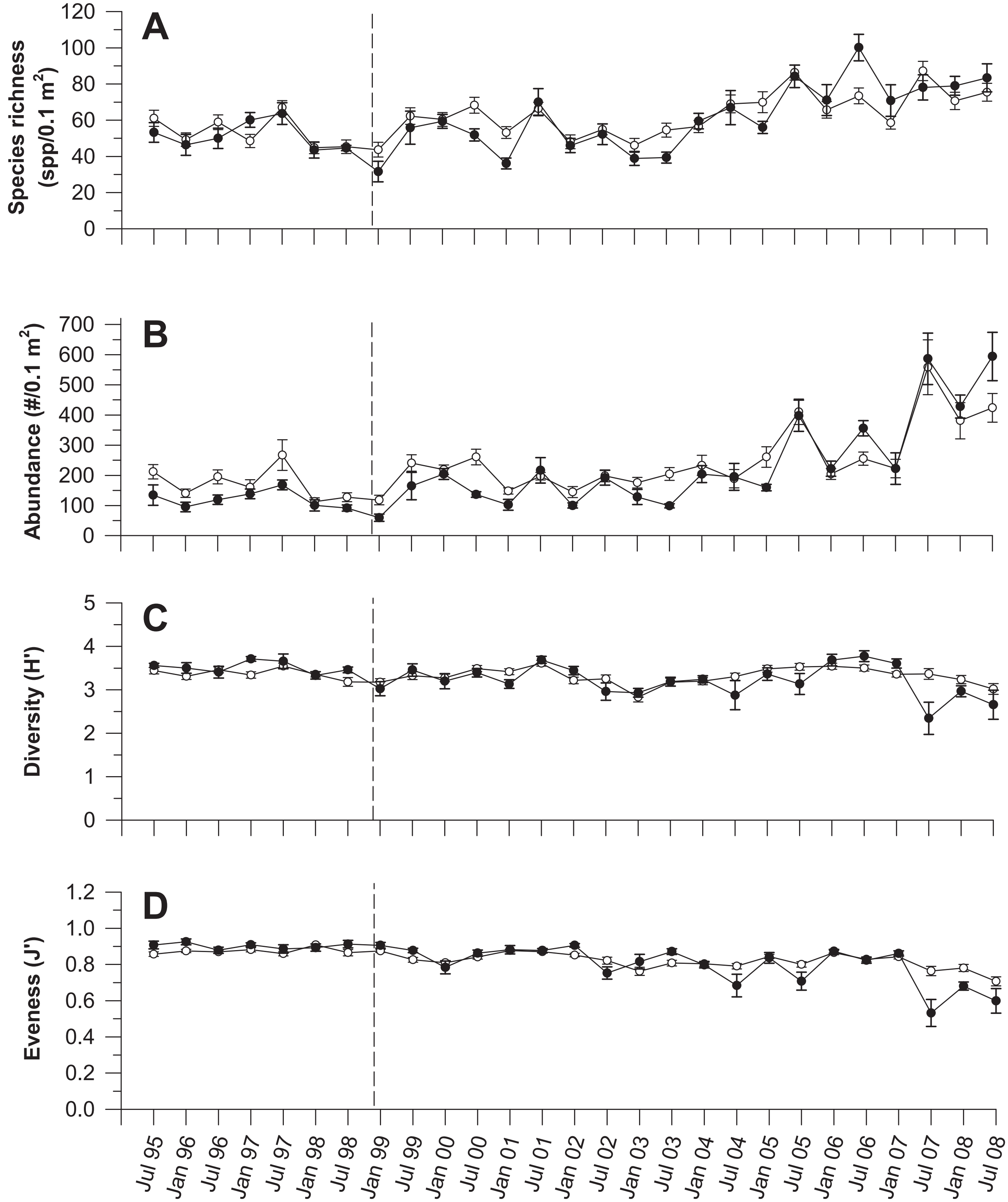


Figure 5.2

Summary of benthic community structure parameters surrounding the South Bay Ocean Outfall from 1995–2008: (A) Species richness; (B) Abundance; (C) Diversity=Shannon diversity index (H'); (D) Eveness=Pielou's evenness index (J'); (E) Swartz dominance index; (F) Benthic response index (BRI). Data are expressed as means per 0.1 m^2 pooled over nearfield stations (dark circles, n=8) versus farfield stations (open circles, n=46) for each survey. Error bars represent standard errors. Dashed line indicates onset of discharge from the SBOO.

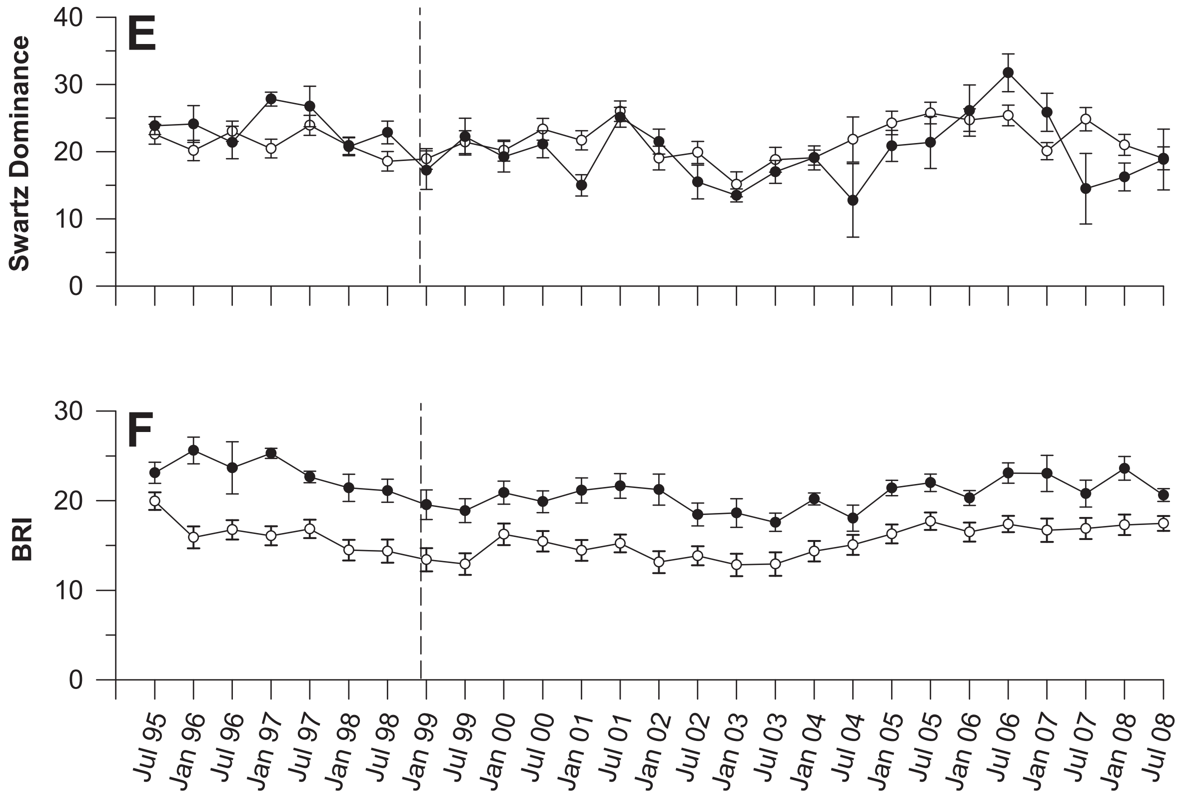


Figure 5.2 *continued*

Macrofaunal abundance

A total of 45,203 macrofaunal individuals were counted in 2008 with mean abundance values ranging from 131 to 1203 animals per 0.1 m^2 sample (Table 5.1). The greatest number of animals occurred at stations I6 and I34, which averaged 1203 and 887 individuals per sample, respectively. In contrast, the fewest number of animals occurred at station I7 (131/0.1 m^2). Average abundance values were about 14% higher during the summer survey than in the winter (Figure 5.2A). Some of this increase was due to large populations of the spionid polychaete *Spiophanes bombyx*, which accounted for 39% of all macrofauna collected in July versus 30% in January (see 'Dominant Species' section below).

Polychaetes were the most numerous animals in the SBOO region during the year, accounting for over 50% of the macrobenthic fauna at the individual sites. Crustaceans were the next most abundant, followed in decreasing order by molluscs, miscellaneous phyla (combined), and echinoderms (Table 5.2).

Species diversity and dominance

Species diversity (H') varied during 2008, ranging from 1.8 to 4.4 (Table 5.1). Average diversity values in the region were generally similar to previous years, and there were no apparent patterns relative to distance from the outfall discharge site (Figure 5.2C). Evenness (J') compliments diversity, with higher J' values (on a scale of 0–1) indicating that species are more evenly distributed (i.e., not dominated by a few highly abundant species). The spatial patterns in evenness were similar to those for diversity, and J' values ranged from 0.44 to 0.89 (Figure 5.2F). Sites with evenness values below the mean of 0.73 were dominated by polychaetes.

Swartz dominance is calculated as the minimum number of species whose combined abundance accounts for 75% of the individuals in a sample (Swartz et al. 1986, Ferraro et al. 1994). Therefore, lower index values (i.e., fewer species) indicate higher numerical dominance. Values at the individual SBOO stations averaged between 5 and 49 species per station during the year (Table 5.1). This range reflects the dominance of

Table 5.2

The percent composition of species and abundance by phyla for SBOO stations sampled during 2008. Data are expressed as annual means (range) for all stations combined (n=27).

Phyla	Species (%)	Abundance (%)
Annelida (Polychaeta)	53 (45-62)	78 (51-92)
Arthropoda (Crustacea)	20 (10-27)	10 (2-24)
Mollusca	14 (9-21)	6 (1-20)
Echinodermata	5 (2-10)	2 (1-7)
Other Phyla	8 (4-15)	4 (2-13)

a few species at some sites (e.g., stations I2, I3, I6, I15, I34) versus other stations where many taxa contributed to the overall abundance (e.g., I28, I29). Overall, Swartz dominance values for 2008 were similar to historical values with no clear patterns evident relative to the outfall (Figure 5.2D).

Benthic Response Index (BRI)

BRI values averaged from 7 to 30 at the various SBOO stations during 2008 (Table 5.1). Index values below 25 (on a scale of 100) are considered to represent undisturbed communities or "reference conditions," while those between 25–34 represent "a minor deviation from reference conditions," the latter which may reflect anthropogenic impact (Smith et al. 2001). Stations I33 and I35 were the only stations with a BRI value above 25 (i.e., 26 and 30, respectively). In 2008, there was no gradient of BRI values relative to distance from the outfall, and index values at sites nearest the discharge site did not suggest any deviation from reference conditions. Since monitoring first began in July 1995, mean BRI values at the four nearfield stations (I12, I14, I15, I16) have been slightly higher than mean BRI values of the farfield stations combined (Figure 5.2E). This pattern has remained consistent over time, including the period prior to January of 1999 when wastewater discharge was initiated through the SBOO. The difference is likely due to the effects of lower BRI values at the 38-m and 55-m stations on the farfield mean BRI (see Smith et al. 2001 for a discussion of the influence of depth on the BRI).

Dominant Species

All monitoring sites in the SBOO region were dominated by polychaete worms. For example, polychaetes comprised all of the 10 most abundant and most frequently occurring species (Table 5.3). The most abundant species collected was the spionid polychaete *Spiophanes bombyx,* which occurred at 100% of the stations and averaged 147 (4–1647) individuals per sample. While *S. bombyx* was ubiquitous in the SBOO region, abundances at individual stations varied. For example, two stations (I6 in January and I34 in July) had much higher abundances than the others in the region, with a combined total of 5378 individuals. Overall, *S. bombyx* accounted for about 35% (15,873) of the macrobenthic fauna sampled during 2008, which was similar to that recorded in 2007 (Figure 5.3).

Few macrobenthic species were widely distributed, and of these only the polychaetes *Spiophanes bombyx*, *Scoloplos armiger* complex, *Mediomastus* sp, and *Monticellina siblina* occurred in 80% or more of the samples. Two of the most frequently collected species were also among the top 10 most abundant taxa (i.e., *S. bombyx* and *M. siblina*). In contrast, the phyllodocid polychaete *Hesionura coineaui difficilis* was found in relatively high numbers at only one station, I34, where sediments were comprised almost entirely of sand and coarse materials.

Classification of Macrobenthic Assemblages

Results of the ordination and cluster analyses discriminated five habitat-related macrobenthic assemblages (see Figure 5.4). These assemblages (cluster groups A–E) varied in terms of their species composition (i.e., specific taxa present) and the relative abundance of those species, and occurred at sites separated by different depths and/or sediment types (microhabitats). The SIMPROF procedure

Table 5.3

The 10 most abundant macroinvertebrates collected at the SBOO benthic stations sampled during 2008. Abundance values are expressed as mean number of individuals per 0.1-m^2 grab sample.

Species	Higher taxa	Percent occurrence	Abundance per sample	Abundance per occurrence
Spiophanes bombyx	Polychaeta: Spionidae	100	147.0	147.0
Monticellina siblina	Polychaeta: Cirratulidae	81	22.4	27.5
Euclymeninae sp A	Polychaeta: Maldanidae	78	8.5	10.9
Spiophanes duplex	Polychaeta: Spionidae	74	7.9	10.7
Spiophanes berkeleyorum	Polychaeta: Spionidae	74	5.3	7.2
Nereis sp A	Polychaeta: Nereidae	76	5.3	7.0
Mediomastus sp	Polychaeta: Capitellidae	83	5.3	6.4
Prionospio (*Prionospio*) *jubata*	Polychaeta: Spionidae	72	4.4	6.1
Scoloplos armiger complex	Polychaeta: Orbiniidae	89	4.2	4.7
Hesionura coineaui difficilis	Polychaeta: Phyllodocidae	19	3.8	20.3

indicated statistically significant non-random structure among samples (π=6.59, p<0.001), and an MDS ordination of the station/survey entities supported the validity of the cluster groups (Figure 5.4B). SIMPER analysis was used to identify species that were characteristic, though not always the most abundant, of each assemblage; the top three characteristic species for each cluster group are indicated in Figure 5.4A. These analyses identified no patterns that could be attributed to proximity to the SBOO discharge site, but showed some separation based on depth gradients (Figure 5.5). Further, the distribution of cluster groups varied based on sediment types, and to some degree, the concentration of total organic carbon present in sediments (Figure 5.6). A complete list of all species comprising each group can be found in Appendix D.1.

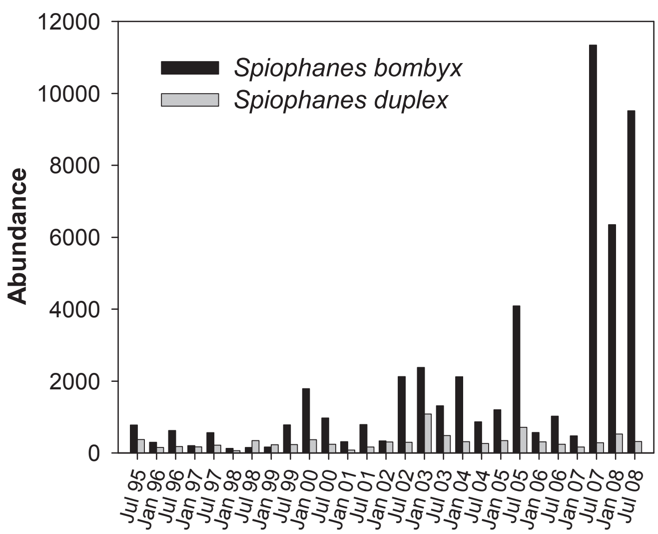
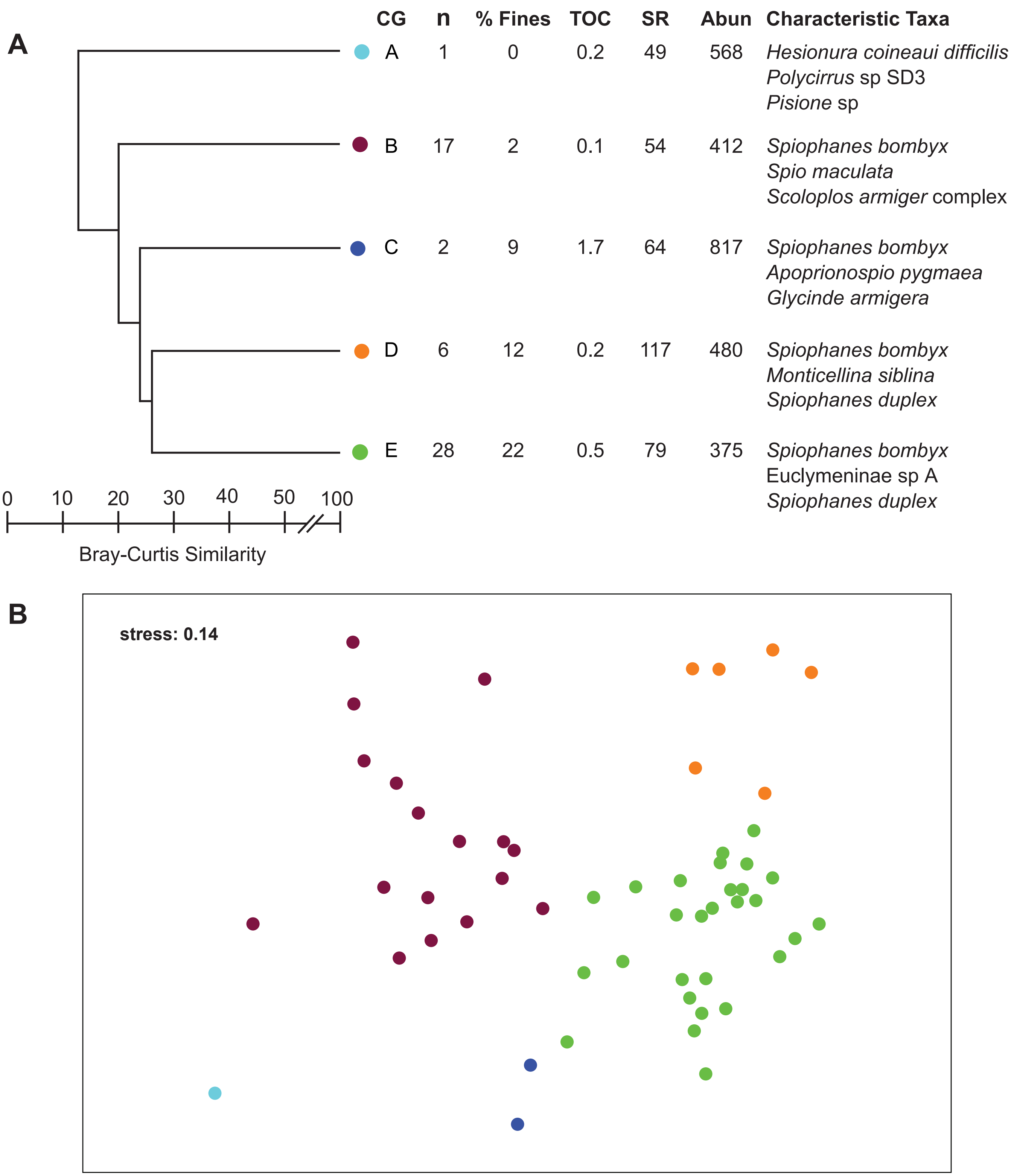


Figure 5.3

Total abundance of the polychaetes *Spiophanes bombyx* and *Spiophanes duplex* for each survey at the SBOO benthic stations from 1995–2008.

Cluster group A represented a shallow-shelf assemblage restricted to the January survey at one station (I34) associated with very coarse sediments. The associated sediments were comprised almost entirely of sand and shell hash (i.e., <1% fines), with total organic carbon (TOC) at 0.2% wt. Species richness averaged 49 taxa and abundance averaged 568 individuals per 0.1 m^2. As in previous years, this assemblage was somewhat unique for the region (see City of San Diego 2007, 2008); it was characterized by several polychaete species commonly found in sediments with coarse particles (e.g., *Hesionura coineaui difficilis*, *Protodorvillea gracilis*, and *Pisione* sp). *Branchiostoma californiense* (Chordata), also associated with coarse sediment habitats, was abundant as well (Appendix D.1).



CG	n	% Fines	TOC	SR	Abun	Characteristic Taxa
A	1	0	0.2	49	568	*Hesionura coineaui difficilis* *Polycirrus* sp SD3 *Pisione* sp
B	17	2	0.1	54	412	*Spiophanes bombyx* *Spio maculata* *Scoloplos armiger* complex
C	2	9	1.7	64	817	*Spiophanes bombyx* *Apoprionospio pygmaea* *Glycinde armigera*
D	6	12	0.2	117	480	*Spiophanes bombyx* *Monticellina siblina* *Spiophanes duplex*
E	28	22	0.5	79	375	*Spiophanes bombyx* Euclymeninae sp A *Spiophanes duplex*

Figure 5.4

(A) Cluster results of the macrofaunal abundance data for the SBOO benthic stations sampled during winter and summer 2008. Data for percent fines, total organic carbon (TOC), species richness (SR), and infaunal abundance (Abun), are expressed as mean values per 0.1-m^2 grab over all stations in each group. (B) MDS ordination based on square-root transformed macrofaunal abundance data for each station/survey entity. Cluster groups superimposed on station/surveys illustrate a clear distinction between faunal assemblages.

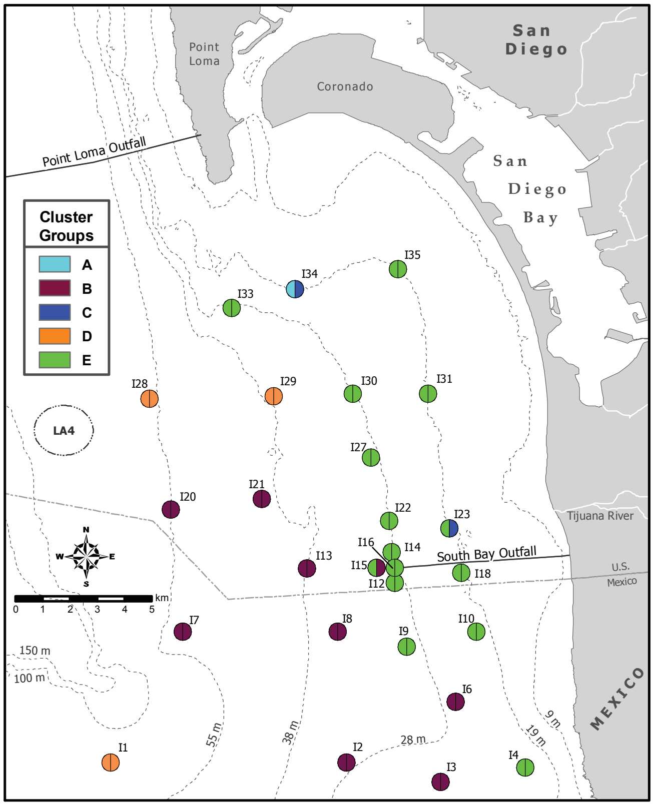


Figure 5.5

Spatial distribution of SBOO macrobenthic assemblages delineated by ordination and classification analyses. Left half of circle represents cluster group affiliation for the January survey; right half represents the July survey.

Cluster group B represented an assemblage that averaged 54 taxa and 412 organisms per 0.1 m^2. This assemblage occurred at nine stations located mostly south of the outfall spanning the 28, 38, and 55-m depth contours. Polychaetes were numerically dominant, with *Spiophanes bombyx, Spio maculata*, and *Scoloplos armiger* complex representing the three most characteristic taxa. The habitat at these sites was characterized by mixed sediments containing coarse particles, especially relict red sand, and TOC concentrations that averaged 0.1 % wt.

Cluster group C represented a shallow-shelf assemblage that occurred at two stations (I23, I34) sampled in July and located along the 19-m depth contour. This assemblage averaged 64 taxa and 817 individuals per 0.1 m^2. *Spiophanes bombyx* was characteristic of this group, as were two other polychaetes, another spionid *Aprionospio pygmaea* and the goniadid *Glycinde armigera*. Sediments at these two sites were characterized by a low percentage of fines (9%) and contained shell hash, while the TOC average concentration of 1.7% was the highest of all groups.

Cluster group D represented a mid-shelf assemblage present at three stations located near the 55 and 38-m depth contours. This assemblage averaged 480 individuals and 117 taxa per 0.1 m^2, the latter representing the highest species richness for the region. The three most characteristic species were polychaetes, and included the spionids *S. bombyx* and *S. duplex*, and the cirratulid *Monticellina siblina*. Sediments at these three sites averaged 12% fines with TOC concentrations of 0.2 % wt.

Cluster group E represented the dominant macrobenthic assemblage present in the SBOO region during 2008, occurring at 15 different stations located along the 19 and 28-m depth contours. This shallow shelf assemblage averaged 79 taxa and 375 individuals per 0.1 m^2. The top three characteristic species for this assemblage included *S. bombyx* and *S. duplex*, as well as another polychaete, the maldanid Euclymeninae sp A. The sediments characteristic of these samples contained higher amounts of fine particles (i.e., mean=22%) than for the other groups (i.e., 0–12%), and had TOC concentrations averaging 0.5 % wt.

Summary and Conclusions

Benthic macrofaunal assemblages surrounding the SBOO were similar in 2008 to those that occurred during previous years, including the period before initiation of wastewater discharge (e.g., see City of San Diego 2000, 2008). In addition, these assemblages were typical of those occurring in other sandy, shallow-, and mid-depth habitats throughout the Southern California Bight (SCB) (e.g., Thompson et al. 1987, 1993b; City of San Diego 1999, Bergen et al. 2001, Ranasinghe et al. 2003, 2007). For example, assemblages found at the majority of stations (i.e., groups B and E) contained high numbers of the spionid polychaete *Spiophanes bombyx*, a species characteristic of

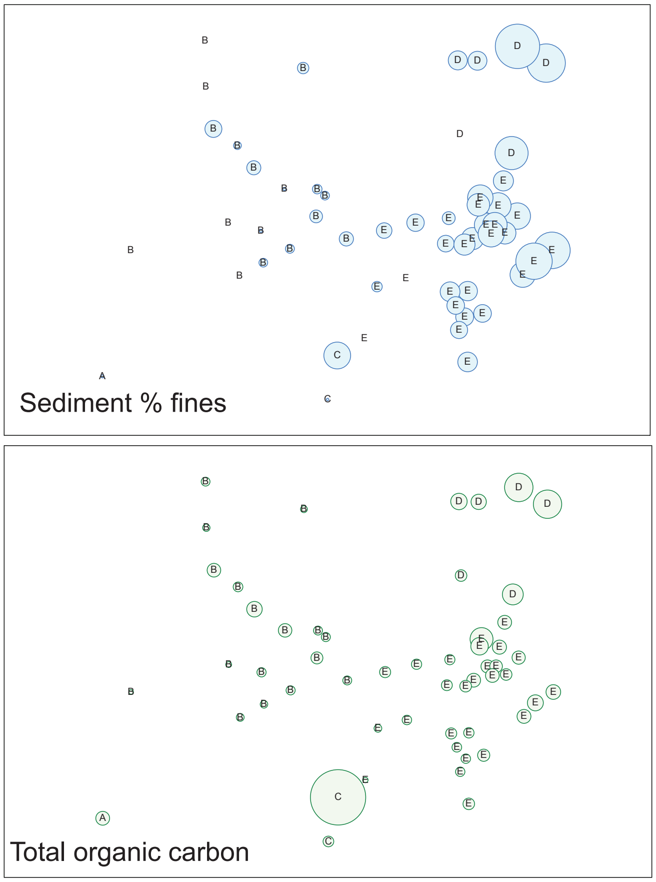


Figure 5.6
MDS ordination of SBOO benthic stations sampled during winter and summer 2008. Cluster groups A–E are superimposed on station/surveys. Percentages of fine particles and total organic carbon in the sediments are further superimposed as circles that vary in size according to the magnitude of each value. Plots indicate associations of benthic assemblages with habitats that differ in sediment grain size and TOC. Stress=0.14.

shallow-water environments with coarser sediments in the SCB (see Bergen et al. 2001). These two groups represented sub-assemblages of the SCB benthos that differed in the relative abundances of dominant and co-dominant species. Such differences probably reflect variation in sediment structure. Consistent with historical values, sediments in the shallow SBOO region generally were coarser south of the outfall relative to the more northern stations (see Chapter 4). In contrast, the group D assemblage occurs in mid-depth shelf habitats that probably represent a transition between the shallow sandy sediments common in the area and the finer mid-depth sediments characteristic of much of the SCB mainland shelf (see Barnard and Ziesenhenne 1961, Jones 1969, Fauchald and Jones 1979, Thompson et al. 1987, 1993a, b; EcoAnalysis et al. 1993, Zmarzly et al 1994, Diener and Fuller 1995, Bergen et al. 2001). The group A assemblage, restricted to station I34 located at the northern end of the SBOO region just south of the entrance to San Diego Bay, was different from assemblages found at any other station. Several species of polychaete worms (i.e., *Polycirrus* sp SD3, *Protodorvillea gracilis*, *Hesionura coineaui difficilis*, *Micropodarke dubia*, *Typosyllis* sp SD1, and *Pisione* sp) not common elsewhere in the region were characteristic of this assemblage. This pattern is similar to that observed previously at this station from 2003 through 2007 (see City of San Diego 2004–2008). Analysis of sediment quality data provides some evidence relevant to explaining the occurrence of both the group A and group C assemblages, which represented only a few samples from two different stations (I23 and I34; see Figure 5.6); mean grain sizes at these sites were the highest measured among all stations for 2008 (see Chapter 4).

Results from multivariate analyses revealed no clear spatial patterns relative to the ocean outfall. Comparisons of the biotic data to the physico-chemical data indicated that macrofaunal distribution and abundance in the region varied primarily along gradients of depth and sediment type and to a lesser degree, levels of organic carbon in the sediments (see Hyland et al. 2005 for a discussion on TOC as an indicator of benthos stress). Populations of the spionid polychaete *Spiophanes bombyx* collected during 2008 were the second highest recorded since monitoring began in 1995. Consequently, the high numbers for this species influenced overall abundance values in the SBOO region. Patterns of region-wide abundance fluctuations over time appear to mirror historical patterns of *S. bombyx* (see Figures 5.2A and 5.3). However, temporal fluctuations in the populations of this and similar species occur elsewhere in the region and can correspond to large-scale oceanographic conditions (see Zmarzly et al. 1994). Overall, analyses of temporal patterns suggest that the benthic community in the South Bay region has not been significantly impacted by wastewater discharge. For example, while species richness and total macrofaunal abundance were at or near their historical highs during 2008, values from the four nearfield stations were similar to those located further away (Figure 5.2A, B) (see City of San Diego 2006–2008). Diversity (H') and evenness (J') values have also remained relatively stable since monitoring began in 1995 (Figure 5.2C, 5.2D). In addition, environmental disturbance index values such as the BRI continue to be generally characteristic of assemblages from undisturbed habitats.

Anthropogenic impacts are known to have spatial and temporal dimensions that can vary depending on a range of biological and physical factors. Such impacts can be difficult to detect, and specific effects of the SBOO discharge on the local macrobenthic community could not be identified during 2008. Furthermore, benthic invertebrate populations exhibit substantial spatial and temporal variability that may mask the effects of any disturbance event (Morrisey et al. 1992a, b; Otway 1995). Although some changes have occurred near the SBOO over time, benthic assemblages in the area remain similar to those observed prior to discharge and to natural indigenous communities characteristic of similar habitats on the southern California continental shelf.

Literature Cited

Barnard, J.L. and F.C. Ziesenhenne. (1961). Ophiuroidea communities of southern Californian coastal bottoms. Pacific Naturalist, 2: 131–152.

Bergen, M., S.B. Weisberg, R.W. Smith, D.B. Cadien, A. Dalkey, D.E. Montagne, J.K. Stull, R.G. Velarde, and J.A. Ranasinghe. (2001). Relationship between depth, sediment, latitude, and the structure of benthic infaunal assemblages on the mainland shelf of southern California. Marine Biology, 138: 637–647.

Bilyard, G.R. (1987). The value of benthic infauna in marine pollution monitoring studies. Marine Pollution Bulletin, 18(11): 581-585.

City of San Diego. (1998). International Wastewater Treatment Plant 1997–1998 Baseline Ocean Monitoring Report. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (1999). San Diego Regional Monitoring Report for 1994–1997. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2000). Final Baseline Monitoring Report for the South Bay Ocean Outfall (1995–1998). City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2004). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall, 2003. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2005). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall, 2004. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2006). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall, 2005. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2007). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall, 2006. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2008). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall, 2007. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Clarke, K.R. (1993). Non-parametric multivariate analyses of changes in community structure. Australian Journal of Ecology, 18: 117–143.

Clarke, K.R. and M. Ainsworth. (1993). A method of linking multivariate community structure to environmental variables. Marine Ecology Progress Series 92: 205-209.

Clarke, K.R. and R.N. Gorley. (2006). PRIMER v6: User Manual/Tutorial. PRIMER-E, Plymouth.

Clarke, K.R., P.J. Somerfield, and R.N. Gorley. (2008). Testing of null hypotheses in exploratory community analyses: similarity profiles and biota-environment linkage. Journal of Experimental Marine Biology and Ecology, 366: 56–69.

Diener, D.R. and S.C. Fuller. (1995). Infaunal patterns in the vicinity of a small coastal wastewater outfall and the lack of infaunal community response to secondary treatment. Bulletin of the Southern California Academy of Sciences, 94: 5–20.

EcoAnalysis, Southern California Coastal Water Research Project, and Tetra Tech. (1993). Analyses of ambient monitoring data for the Southern California Bight. Final Report to U.S. EPA, Wetlands, Oceans, and Estuaries Branch, Region IX, San Francisco, CA.

Fauchald, K. and G.F. Jones. (1979). Variation in community structures on shelf, slope, and basin macrofaunal communities of the Southern California Bight. Report 19, Series 2 in: Southern California Outer Continental Shelf Environmental Baseline Study, 1976/1977 (Second Year) Benthic Program. Principal Investigators Reports, Vol. II. Science Applications, Inc. La Jolla, CA.

Ferraro, S.P., R.C. Swartz, F.A. Cole, and W.A. Deben. (1994). Optimum macrobenthic sampling protocol for detecting pollution impacts in the Southern California Bight. Environmental Monitoring and Assessment, 29: 127–153.

Field, J.G., K.R. Clarke, and R.M. Warwick. (1982). A practical strategy for analyzing multiple species distribution patterns. Marine Ecology Progress Series, 8: 37–52.

Gray, J.S. (1979). Pollution-induced changes in populations. Philosophical Transactions of the Royal Society of London (Series B), 286: 545–561.

Hartley, J.P. (1982). Methods for monitoring offshore macrobenthos. Marine Pollution Bulletin, 12: 150–154.

Hyland J., L. Balthis, I. Karakassis, P. Magni, A. Petrov, J. Shine, O. Vestergaard, and R. Warwick. (2005). Organic carbon content of sediments as an indicator of stress in the marine benthos. Marine Ecology Progress Series, 295: 91–103.

Jones, G.F. (1969). The benthic macrofauna of the mainland shelf of southern California. Allan Hancock Monograph of Marine Biology, 4: 1–219.

Morrisey, D.J., L. Howitt, A.J. Underwood, and J.S. Stark. (1992a). Spatial variation in soft-sediment benthos. Marine Ecology Progress Series, 81: 197–204.

Morrisey, D.J., A.J. Underwood, L. Howitt, and J.S. Stark. (1992b). Temporal variation in soft-sediment benthos. Journal of Experimental Marine Biology and Ecology, 164: 233–245.

Otway, N.M. (1995). Assessing impacts of deepwater sewage disposal: a case study from New South Wales, Australia. Marine Pollution Bulletin, 31: 347–354.

Pearson, T.H. and R. Rosenberg. (1978). Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanography and Marine Biology Annual Review, 16: 229–311.

Ranasinghe, J.A., D.E. Montagne, R.W. Smith, T.K. Mikel, S.B. Weisberg, D. Cadien, R. Velarde, and A. Dalkey. (2003). Southern California Bight 1998 Regional Monitoring Program: VII. Benthic Macrofauna. Southern California Coastal Water Research Project. Westminster, CA.

Ranasinghe, J.A., A.M. Barnett, K. Schiff, D.E. Montagne, C. Brantley, C. Beegan, D.B. Cadien, C. Cash, G.B. Deets, D.R. Diener, T.K. Mikel, R.W. Smith, R.G. Velarde, S.D. Watts, S.B. Weisberg. (2007). Southern California Bight 2003 Regional Monitoring Program: III. Benthic Macrofauna. Southern California Coastal Water Research Project. Costa Mesa, CA.

Smith, R.W., M. Bergen, S.B. Weisberg, D. Cadien, A. Dalkey, D. Montagne, J.K. Stull, and R.G. Velarde. (2001). Benthic response index for assessing infaunal communities on the southern California mainland shelf. Ecological Applications, 11(4): 1073–1087.

Snelgrove P.V.R., T.H. Blackburn, P.A. Hutchings, D.M. Alongi, J.F. Grassle, H. Hummel, G. King, I. Koike, P.J.D. Lambshead, N.B. Ramsing, V. Solis-Weiss. (1997). The importance of marine sediment biodiversity in ecosystem processes. Ambio, 26: 578–583.

Swartz, R.C., F.A. Cole, and W.A. Deben. (1986). Ecological changes in the Southern California Bight near a large sewage outfall: benthic conditions in 1980 and 1983. Marine Ecology Progress Series, 31: 1–13.

Thompson, B., J. Dixon, S. Schroeter, and D.J. Reish. (1993a). Chapter 8. Benthic invertebrates. In: M.D. Dailey, D.J. Reish, and J.W. Anderson (eds.). Ecology of the Southern California Bight: A Synthesis and Interpretation. University of California Press, Berkeley, CA.

Thompson, B.E., J.D. Laughlin, and D.T. Tsukada. (1987). 1985 reference site survey. Technical Report No. 221, Southern California Coastal Water Research Project, Long Beach, CA.

Thompson, B.E., D. Tsukada, and D. O'Donohue. (1993b). 1990 reference site survey. Technical Report No. 269, Southern California Coastal Water Research Project, Long Beach CA.

[USEPA] United States Environmental Protection Agency. (1987). Quality Assurance and Quality Control (QA/QC) for 301(h) Monitoring Programs: Guidance on Field and Laboratory Methods. EPA Document 430/9-86-004. Office of Marine and Estuarine Protection.

Warwick, R.M. (1993). Environmental impact studies on marine communities: pragmatical considerations. Australian Journal of Ecology, 18: 63–80.

Zmarzly, D.L., T.D. Stebbins, D. Pasko, R.M. Duggan, and K.L. Barwick. (1994). Spatial patterns and temporal succession in soft-bottom macroinvertebrate assemblages surrounding an ocean outfall on the southern San Diego shelf: Relation to anthropogenic and natural events. Marine Biology, 118: 293–307.

This page intentionally left blank